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Remote sensing plant stress using combined fluorescence and reflectance measurements for early detection of defoliants within the battlefied environment	5a. CONTRACT NUMBER W911NF-06-1-0074
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6. AUTHORS Donald R. Young	5d. PROJECT NUMBER
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Virginia Commonwealth University 800 East Leigh Street, Suite 113 PO Box 980568 Richmond, VA 23298 -0568	
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12. DISTRIBUTION AVAILIBILITY STATEMENT

Approved for Public Release; Distribution Unlimited

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14. ABSTRACT

Leaf fluorescence spectral characteristics were fused with reflectance hyperspectral data to remotely sense vegetation/terrain conditions. Field measurements were conducted at the Virginia Coast Reserve, NSF, long-term ecological research site and at Ft. A.P. Hill. Laboratory experiments and field measurements incorporated relevant battlefield contaminants and natural environmental stresses. Goals were to 1) link leaf fluorescence and reflectance patterns and plant physiological responses with different kinds and degrees of environmental stress, 2) predict the

15. SUBJECT TERMS

Chlorophyll fluorescence, leaf reflectance, hyperspectral, remote sensing, environmental stress, photosynthesis, water relations, battlefield environment, environmental conditions, UXOs, TNT

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Donald Young
UU	UU	UU	UU		19b. TELEPHONE NUMBER 804-828-1562

Report Title

Remote sensing plant stress using combined fluorescence and reflectance measurements for early detection of defoliants within the battlefied environment

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Leaf fluorescence spectral characteristics were fused with reflectance hyperspectral data to remotely sense vegetation/terrain conditions. Field measurements were conducted at the Virginia Coast Reserve, NSF, long-term ecological research site and at Ft. A.P. Hill. Laboratory experiments and field measurements incorporated relevant battlefield contaminants and natural environmental stresses. Goals were to 1) link leaf fluorescence and reflectance patterns and plant physiological responses with different kinds and degrees of environmental stress, 2) predict the stress agent and degree of stress using leaf fluorescence and reflectance characteristics, 3) extend laboratory results to field situations to link field measurements of leaf fluorescence and reflectance to natural environmental stress, 4) use plant physiological measurements in conjunction with leaf fluorescence and reflectance data to sort and identify potential stress agents in the field, and 5) link landscape level hyperspectral measurements to spatial variations in leaf fluorescence and reflectance in order to map environmental quality. In year four, added objectives were 1) determine if exposure to trinitrotoluene (TNT) contaminated soils and associated changes in plant physiological parameters can be remotely sensed, 2) identify highly responsive species to serve as contamination indicators, and 3) link landscape level hyperspectral measurements to experimental results to remotely identify (TNT) contaminated soils,

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Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Naumann, JC, DR Young and JE Anderson. 2007. Linking fluorescence, reflectance and physiological responses to environmental stress. Invited presentation at the Workshop on Vegetation Stress Detection with Remote Sensing Imagery, Instituto de Agricultura Sostenible, Córdoba, Spain

Young, D.R. 2007. Leaf to landscape in a barrier island environment." Workshop on Vegetation Stress Detection with Remote Sensing Imagery, Instituto de Agricultura Sostenible, Córdoba, Spain

Young, D.R. and J.C. Naumann. 2007. Fluorescence remote sensing detection of stress in the evergreen shrub, Myrica cerifera. Army Research Office Terrestrial Sciences Program PI Review, Vicksburg, MS

Naumann, JC, DR Young and JE Anderson. 2008. Spatial variations in salinity stress across a coastal landscape. Presentation at Ecological Society of America, Milwaukee, WI

Brantley ST, Naumann JC and DR Young. 2009. Application of hyperspectral vegetation indices to detect variations in leaf area index in Morella cerifera and Elaeganus umbellata shrub thickets. Presentation at Association of Southeastern Biologists, Asheville, NC

Naumann, JC, DR Young and JE Anderson. 2009. Using plant canopies to detect TNT contamination in soil. Presentation at Ecological Society of America, Albuquerque, NM

Naumann JC, DR Young and JE Anderson. 2009. Linking chlorophyll fluorescence, hyperspectral reflectance and plant physiological responses to detect stress using the photochemical reflectance index (PRI). Invited presentation in Remote Sensing of Vegetation Processes, American Geophysical Union, San Francisco, CA

Naumann JC, JE Anderson and DR Young. 2009. Remote sensing and plant physiological responses to TNT soil contamination. Poster at USACE ERDC Conference, Memphis, TN

Young DR, Naumann JC and JE Anderson. 2009. Remote sensing of plant stress in shrubs using combined fluorescence and canopy reflectance measurements. Poster at USACE ERDC Conference, Memphis, TN

Naumann JC, Vick JK*, Nelson JD, Hoffman A1 and DR Young. 2010. Atypical chlorophyll responses to stress in a high light coastal environment. Presentation at Ecological Society of America, Pittsburgh, PA

Number of Presentations: 10.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper
10/01/2012	8.00 JC_Naumann, K_Rubis, DR_Young. Fusing chlorophyll fluorescence and plant canopy reflectance to detect TNT contamination in soils, SPIE 7664. 2010/04/07 00:00:00, . : ,

TOTAL: **1**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received	Paper

TOTAL:

Number of Manuscripts:

Books

Received	Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Julie Zinnert	0.50	
Steven Brantley	0.25	
Jaclyn Vick	0.00	
Spencer Bissett	0.10	
FTE Equivalent:	**0.85**	
Total Number:	**4**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Donald R. Young	0.08	
FTE Equivalent:	**0.08**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
Kathryn Rubis	0.20	Biosciences
FTE Equivalent:	**0.20**	
Total Number:	**1**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 1.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 1.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 1.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 1.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 1.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME	
Julie C Naumann	
Total Number:	**1**

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Objectives

The project goal was to fuse leaf fluorescence and reflectance characteristics to remotely sense vegetation and terrain conditions. The project objectives were:

- For multiple species, link leaf reflectance and fluorescence patterns with different causes and degrees of plant stress.
- Extend glasshouse/laboratory results to field situations to link field measurements of leaf fluorescence and reflectance to natural environmental stress.
- Under field conditions and with potential multiple environmental stresses, use measurements of photosynthesis, plant water status, leaf fluorescence and reflectance to "sort" and identify the forms of stress.
- Link landscape level hyperspectral measurements to spatial variations in leaf fluorescence and reflectance to map environmental quality.
- Effectively characterize plant stress as a terrestrial indicator for both civil and military (e.g. mobility) applications

The Add-on objectives were:

- Use glasshouse/laboratory experiments to determine if exposure to TNT contaminated soils and associated changes in plant physiological parameters can be remotely sensed.
- Identify highly responsive species to serve as contamination indicators.
- Link landscape level hyperspectral measurements to experimental results to remotely identify TNT contaminated soils.

Accomplishments

- Laboratory measurements with the evergreen shrub, Myrica cerifera, and with the invasive grass, Phragmites australis, indicate that light-adapted fluorescence measurements have been successful in all experiments at detecting stress prior to visible signs of damage.
- Regardless of concentration, treatments with the surrogate nerve agent (i.e. insecticide) did not induce detectable physiological stress or changes in fluorescence or reflectance characteristics.
- Reflectance characteristics were effective at tracking changes in light-adapted fluorescence at the leaf-level scale. Thus, variations in physiological responses were linked to changes in chlorophyll fluorescence which were linked to differences in reflectance patterns. These results are promising for linking fluorescence to reflectance for rapid detection of stress in plants through remote sensing of hyperspectral imagery.
- When applied at the canopy level, the relationships identify environmental variations across the landscape as indicated by stress and associated stressors in plants prior to visible signs of damage.
- From the combined field and hyperspectral data collection, and using the results of our laboratory studies, we have established links between the remotely sensed data and environmental conditions in the field as projected by our indicator plant species. We have identified spatial variations in salt stress, seasonal changes in drought stress and year to year variations in vegetation stress.
- For laboratory experiments, several reflectance indices and the chlorophyll fluorescence response were able to detect TNT induced stress in plants before changes in leaf pigments or visible damage occurred.
- Field studies at the Duck, NC Field Research Facility revealed differences in plant physiological stress and leaf and canopy reflectance when plants growing over suspected buried UXOs were compared with reference plants.

Technology Transfer

- This project includes frequent communications and collaborations with the ERDC TEC lab in northern Virginia. We regularly visit their facility to discuss progress and to share information. All phases of this project, including results and conclusions are readily accessible to their staff. For example, Dr. Anderson has used our laboratory results to develop a light adapted algorithm that is a modified version of the European Space Agency's dark-adapted plant model for remotely sensing stress at the plant canopy level.
- Dr. John Anderson and his associates maintain a remote office and a research laboratory in the VCU Trani Life Sciences Building. Dr. Julie Zinnert (Naumann) maintains an office and regularly works in Dr. Anderson's lab, my lab, and the VCU greenhouse facility
- I and my students interact with Dr. Zinnert, Dr. Anderson, and their associates on a weekly basis.
- The natural interactions between the PI's lab at VCU and the staff at the ERDC-TEC lab ensure a seamless transition of data and results.

Technology Transfer

2010 Project Summary/Final Report

Remote sensing plant stress using combined fluorescence and reflectance measurements for early detection of defoliants within the battlefield environment

ARO Proposal # (49364-EV)

Donald R. Young
Department of Biology
Virginia Commonwealth University

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Peer-Reviewed Publications

- Naumann, J.C., D.R. Young, and J.E. Anderson. 2007. Linking leaf chlorophyll fluorescence properties to physiological responses for stress detection in coastal plant species. Physiologia Plantarum 131: 422-433.
- Naumann, J.C., D.R. Young, and J.E. Anderson. 2008. Leaf fluorescence, reflectance, and physiological response to freshwater and saltwater flooding in the evergreen shrub, *Myrica cerifera*. Environmental and Experimental Botany 63: 402-409.

- Naumann, J.C., J.E. Anderson, and D.R. Young. 2008. Linking physiological responses, chlorophyll fluorescence and hyperspectral imagery to detect salinity stress using the physiological reflectance index in the coastal shrub, *Myrica cerifera*. Remote Sensing of Environment. 112: 3865-3875.
- Naumann, J.D., D.R. Young, and J.E. Anderson. 2009. Spatial variations in salinity stress across a coastal landscape using vegetation indices derived from hyperspectral imagery. Plant Ecology 202: 285-297.
- Brantley, S.T. and D.R. Young. 2010. Linking light attenuation, sunflecks and canopy architecture in mesic shrub thickets. Plant Ecology 206: 225-236.
- Naumann, J.C., J.E. Anderson and D.R. Young. 2010. Remote detection of plant physiological responses to TNT soil contamination. Plant and Soil 329: 239-248
- Naumann, J.C., S.N. Bissett, D.R. Young, J. Edwards, and J.E. Anderson. 2010. Diurnal patterns of photosynthesis, chlorophyll fluorescence, and PRI to evaluate water stress in the invasive species, *Eleangus umbellata* Thunb. Trees 24: 237–245.
- Naumann, J.C., K. Rubis and D.R. Young. 2010. Fusing chlorophyll fluorescence and plant canopy reflectance to detect TNT contamination in soils. Proceedings of SPIE 7664: 1L-1-7, Orlando, FL.
- Brantley, S.R., J.C. Naumann and D.R. Young. 2011. Application of hyperspectral vegetation indices to detect variations in high leaf area index temperate shrub thicket canopies. Remote Sensing of Environment. 115: 514-523.